NACA L-249

RB No. 3D26

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
April 1943 as
Restricted Bulletin 3D26

A STUDY OF THE EFFECTS OF RADII OF GYRATION AND ALTITUDE ON AILERON EFFECTIVENESS AT HIGH SPEED

By Leo F. Fehlner

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESTRICTED BULLETIN

A STUDY OF THE EFFECTS OF RADII OF GYRATION AND ALTITUDE ON AILERON EFFECTIVENESS AT HIGH SPEED

By Leo F. Fehlner

INTRODUCTION

Because the time to bank combat aircraft has become increasingly important and because information on the variation in the time to bank with altitude and with weight distribution along the wings is not available, the present theoretical investigation was made to determine the magnitude of these effects. The variation in the necessary aileron control and in the time required to bank to 45° and 90° with altitude and radii of gyration for a typical fighter or a pursuit airplane have been computed and are presented herein.

SYMBOLS

V true airspeed, miles per hour

V_i indicated airspeed, miles per hour (correct reading of airspeed indicator calibrated to read true airspeed at zero altitude)

M Mach number

γ longitudinal flight-path angle, degrees

K_X ratio of radius of gyration about the X axis to span

K_Z ratio of radius of gyration about the Z axis to span

t time, seconds

C_l rolling-moment coefficient, $\frac{L}{qS_wb}$

L rolling moment, foot pounds

q dynamic pressure, pounds per square foot

q_c impact pressure, pounds per square foot

S_w wing area, square feet

b span, feet

AIRPLANE CHARACTERISTICS AND METHOD

The total weight of the airplane considered in the computations is 9300 pounds; wing loading, 35 pounds per square foot; aspect ratio, 6; and span, 40 feet. The aerodynamic characteristics were chosen to be representative of pursuit or fighter aircraft in high-speed flight just below the critical speed.

The altitude was varied from 0 to 50,000 feet under standard conditions. The ratio of the radius of gyration about the X axis to the wing span was varied from 0.08 to 0.16 and the ratio of the radius of gyration about the Z axis to the wing span was varied from 0.14 to 0.22. This range of radii-of-gyration ratios covers the complete range of all the values known for 42 existing conventional pursuit and fighter aircraft. The motions of the airplane were studied in vertical dive, high-speed glide, level flight, and climb attitudes at constant Mach number, constant true airspeed, and constant indicated airspeed.

The lateral motions were computed for the cases given in table I.

The impact pressure for the various conditions of flight are given in table II.

The lateral motions of the airplane were determined by solving the differential equations of motion in a manner similar to that used in reference 1. In the present report the ailerons were assumed to be deflected in such a way as to increase uniformly the rolling-moment coefficient applied to the airplane during the first one-tenth second and to hold it constant thereafter.

L-249

RESULTS AND DISCUSSION

The results are presented in figures 1 to 3.

Figure 1 includes three types of variation with altitude: one variation at constant true airspeed, another at constant Mach number, and a third at constant indicated airspeed. Cases for constant true airspeed and constant Mach number are chosen to be identical at 20,000 feet and cases for constant indicated airspeed and constant Mach number are chosen to be identical at 50,000 feet.

Figure 1(a) shows the variation with altitude of the rolling-moment coefficient that must be applied by ailerons to perform two banking maneuvers; namely, the attainment of an angle of bank of 45° at the end of the first half second and 90° at the end of the first second.

Figure 1(b) shows the variation with altitude of the time to bank to 45° and 90°. The rolling-moment coefficients applied at all altitudes are those that produce an angle of bank of 45° at the end of the first half second and of 90° at the end of the first second at zero altitude.

The rolling-moment coefficient necessary to bank to 45° in one-half second is greater than that necessary to bank to 90° in 1 second. This difference in required rolling-moment coefficient is due to the fact that the airplane accelerates in roll during all or a large part of the time intervals considered. The moment of inertia in roll therefore has an important influence on very short rolling maneuvers. The rolling-moment coefficient required to bank to any other angle in the same time is directly proportional to the angle; that is, to bank to 45° in 1 second requires half the rolling-moment coefficient necessary to bank to 90° in 1 second.

The decrease in required rolling-moment coefficient shown for increasing altitude with indicated airspeed constant is caused by the large increase in true airspeed that is required to maintain a given indicated airspeed. (See table I.) The rolling-moment coefficient necessary to bank the airplane in a given time is not a function of velocity alone, however, as is shown by the variation of rolling-moment coefficient with altitude when true airspeed is constant (fig. 1).

At a Mach number of 0.75 and also at a true airspeed of 530 miles per hour, a greater rolling-moment coefficient is required to bank the airplane to 90° in 1 second at high altitudes than at low altitudes. At a Mach number of 0.75 the increase in rolling-moment coefficient required in changing from 20,000 to 40,000 feet is about 40 percent for the airplane considered.

If the hinge moment is assumed to be proportional to the rolling moment, a relative hinge moment may be computed by multiplying the rolling-moment coefficients of figure 1 by the corresponding impact pressures presented in table II. These relative hinge moments are presented in figure 2 in a manner similar to that used for the rolling-moment coefficients of figure 1.

The factor of proportionality between the rolling moment and the hinge moment depends on the aerodynamic characteristics of the particular airplane. The variation of stick force with hinge moment varies with linkage and booster systems. The computation of the variation of stick force with altitude from the hinge-moment variation requires a knowledge of the variation in stick force with hinge moment for a particular case.

The hinge moments applied in figure 2(b) are those that produce an angle of bank of 45° at the end of the first half second and 90° at the end of the first second at zero altitude.

The hinge moment necessary to bank to 45° and 90° in the stated time intervals is greatly decreased by increases in altitude. For the 90° maneuver at a Mach number of 0.75 the hinge moment is 44 percent less at 40,000 feet than at 20,000 feet.

The time to bank to 90° and 45° greatly decreases as altitude increases if the hinge moment is held constant at all altitudes. The decrease in the time to bank to 90° is 30 percent for a change in altitude from 20,000 to 40,000 feet.

Although figure 2(b) does show the variation of the time to bank to given angles with altitude for various constant hinge moments, the corresponding rolling-moment coefficients required at high altitude exceed those obtainable with present designs. The decrease in the time to bank to a given angle as shown in figure 2(b) is therefore limited by the maximum rolling-moment coefficient available.

L-249

From figures 1 and 2, it is concluded that if the strength of the pilot limits the aileron deflection, as is usually the case for present high-speed airplanes, the aileron effectiveness increases with altitude. At a given limiting Mach number, the increase in effectiveness results largely from the larger deflections produced by a given force applied to the stick and the increase in effectiveness will continue only to the altitude at which the maximum design deflection of the aileron is reached. Above this altitude the aileron effectiveness will decrease. The aileron system, therefore, should be designed for rolling-moment requirements at high altitude and the hinge-moment limitations at low altitude.

Figure 3 includes variations of the radius of gyration about the X axis of the airplane in a glide and in level flight at 530 miles per hour and at an altitude of 20,000 feet. The radii of gyration of airplanes of widely different classifications fall within the range of radii of gyration considered. These classifications include all conventional single- and twin-engine pursuit and fighter airplanes with wide variations in weight distribution along the wings.

Figure 3(a) shows the variation with the radius of gyration about the X axis of the rolling-moment coefficient necessary to attain an angle of bank of 45° at the end of the first half second and of 90° at the end of the first second.

Figure 3(b) shows the variation of the time to bank to 45° and 90° with the radius of gyration about the X axis. The rolling-moment coefficients applied for all values of the radius of gyration are those that produce an angle of bank of 45° at the end of the first half second and of 90° at the end of the first second with the ratio of radius of gyration about the X axis to the span equal to 0.08.

The effect of changes in the radius of gyration in roll on the rolling-moment coefficient necessary to bank to 90° in 1 second is large because of the large percentage of the maneuver spent in accelerating the airplane in roll. The rolling-moment requirements are increased about 28 percent by increasing the radius of gyration about the X axis from 0.08 to 0.16.

The effect on the banking maneuvers considered of variations in the radius of gyration about the Z axis are negligible.

The longitudinal flight path was varied from a vertical dive to a 13.9° climb at 530 miles per hour and at 20,000 feet. The effects on the banking maneuver of variations in longitudinal flight path angle are negligible in the range investigated.

For all the assumed conditions of flight, the angle of sideslip resulting from a rolling-moment coefficient of 0.05 deviates in an oscillatory manner during the first 2 seconds and does not exceed an angle of the order of 2°.

Langley Memorial Aeroanutical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va.

REFERENCE

1. Fehlner, Leo F.: A Study of the Effects of Vertical Tail Area and Dihedral on the Lateral Maneuverability of an Airplane. NACA A.R.R., Oct. 1941.

L-249

TABLE I

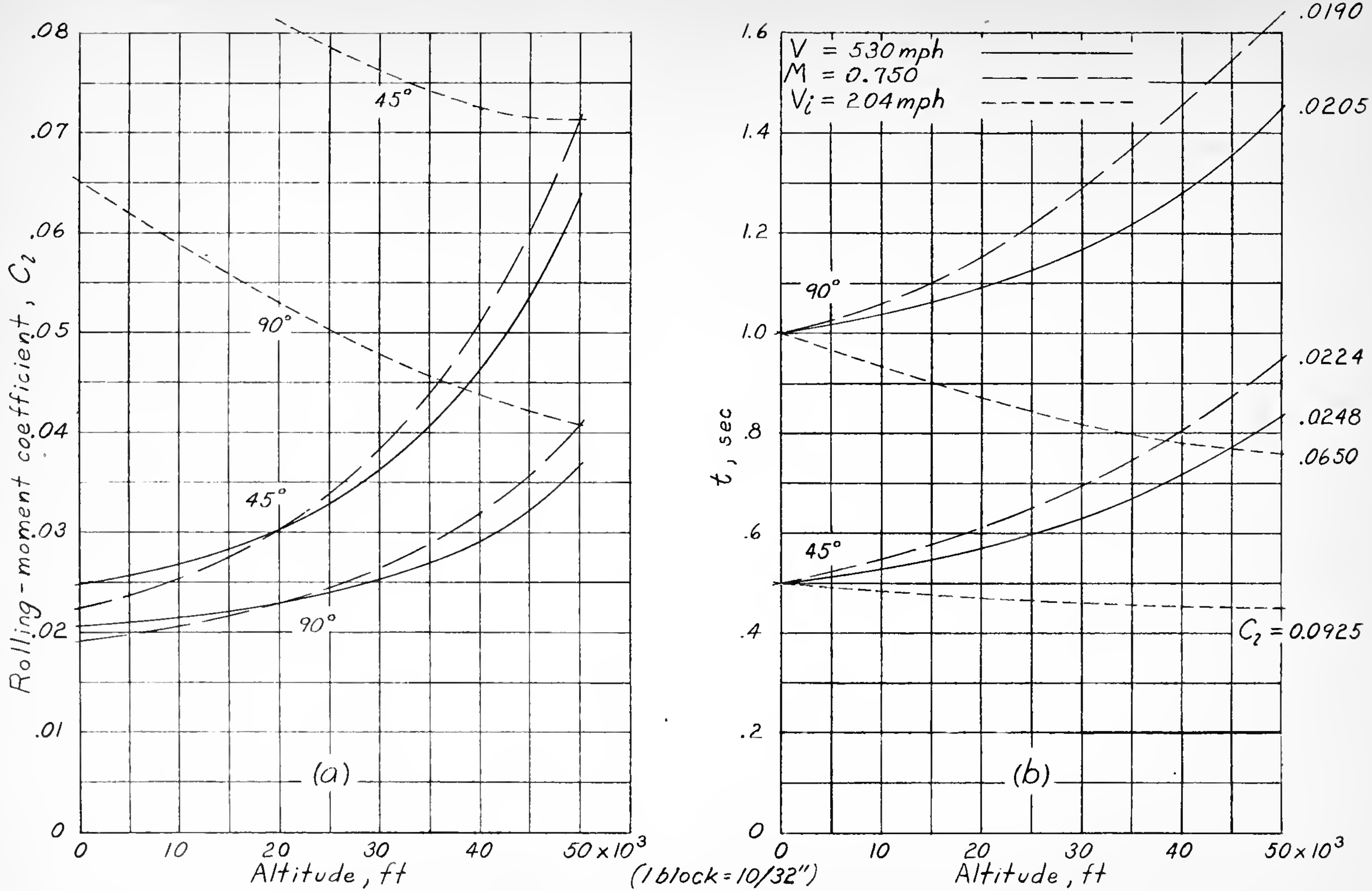
CASES FOR WHICH LATERAL MOTIONS WERE COMPUTED

Case	M	V (mph)	V_i (mph)	Altitude (ft)	γ (deg)	K_X	K_Z	C_L
1	0.750	570	570	0	-30.7	0.125	0.175	0.036
2	.750	530	400	20,000	-13.9	.125	.175	.088
3	.750	496	258	40,000	-6.1	.125	.175	.224
4	.750	496	204	50,000	-4.4	.125	.175	.365
5	.696	530	530	0	-27.0	.125	.175	.042
6	.800	530	278	40,000	-6.7	.125	.175	.198
7	.800	530	220	50,000	-4.8	.125	.175	.320
8	.269	204	204	0	-4.7	.125	.175	.325
9	.394	278	204	20,000	-4.7	.125	.175	.328
10	.602	400	204	40,000	-4.5	.125	.175	.350
11	.750	530	400	20,000	-13.9	.080	.140	.088
12	.750	530	400	20,000	-13.9	.080	.220	.088
13	.750	530	400	20,000	-13.9	.160	.220	.088
14	.750	530	400	20,000	0	.125	.175	.091
15	.750	530	400	20,000	0	.080	.140	.091
16	.750	530	400	20,000	0	.080	.220	.091
17	.750	530	400	20,000	0	.160	.220	.091
18	.750	530	400	20,000	13.9	.125	.175	.088
19	.750	530	400	20,000	-90.0	.125	.175	0

TABLE II

VARIATION OF IMPACT PRESSURE WITH ALTITUDE

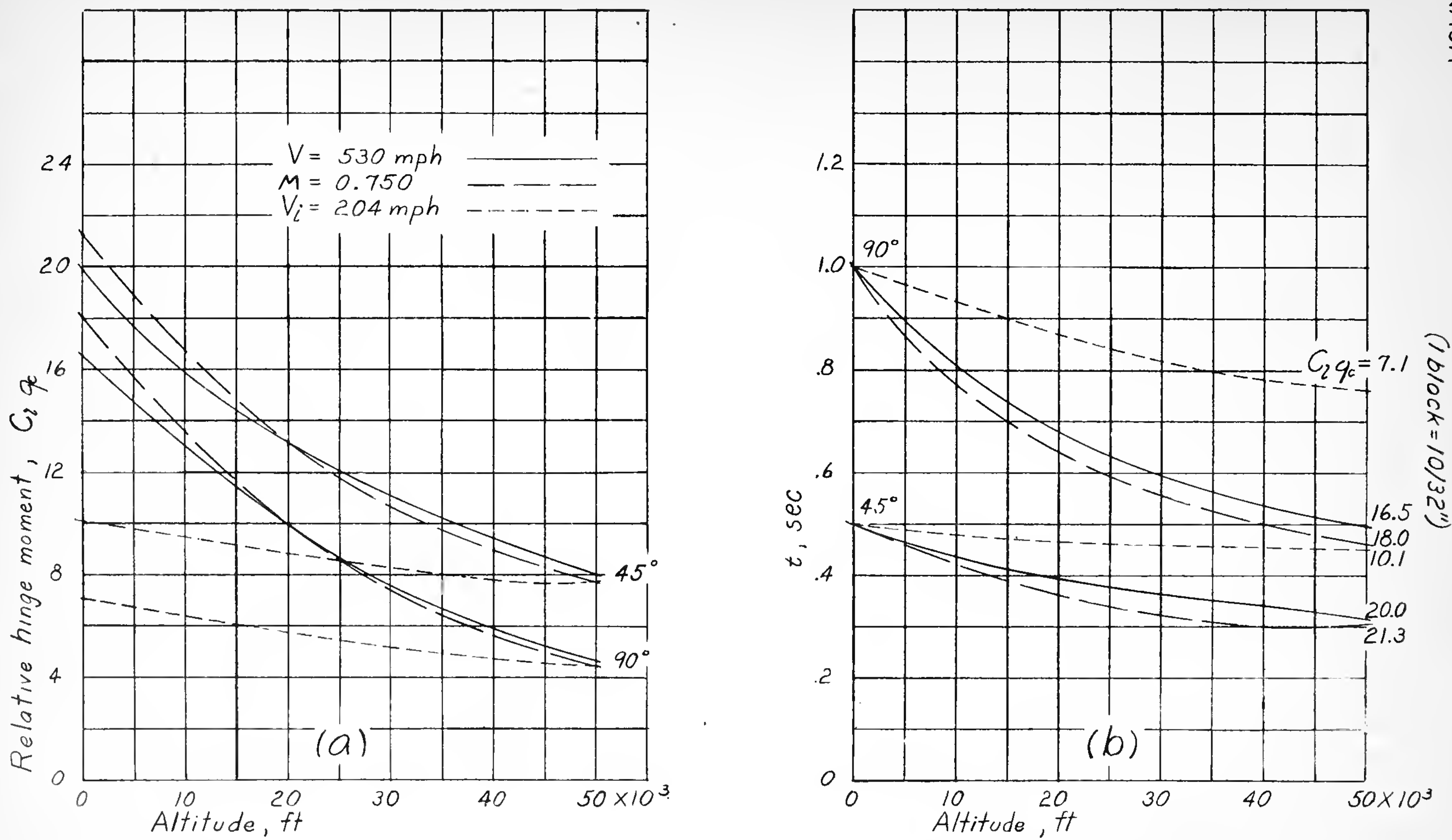
Altitude (ft)	q_c		
	M = 0.750	V = 550 mph	V_i = 204 mph
0	950.0	805.3	109.1
20,000	436.5	436.5	109.1
40,000	176.0	203.9	109.1
50,000	109.1	126.5	109.1



(a) The rolling moment necessary to bank to 45° at the end of the first half second and 90° at the end of the first second.

(b) The time to bank to 45° and 90°.

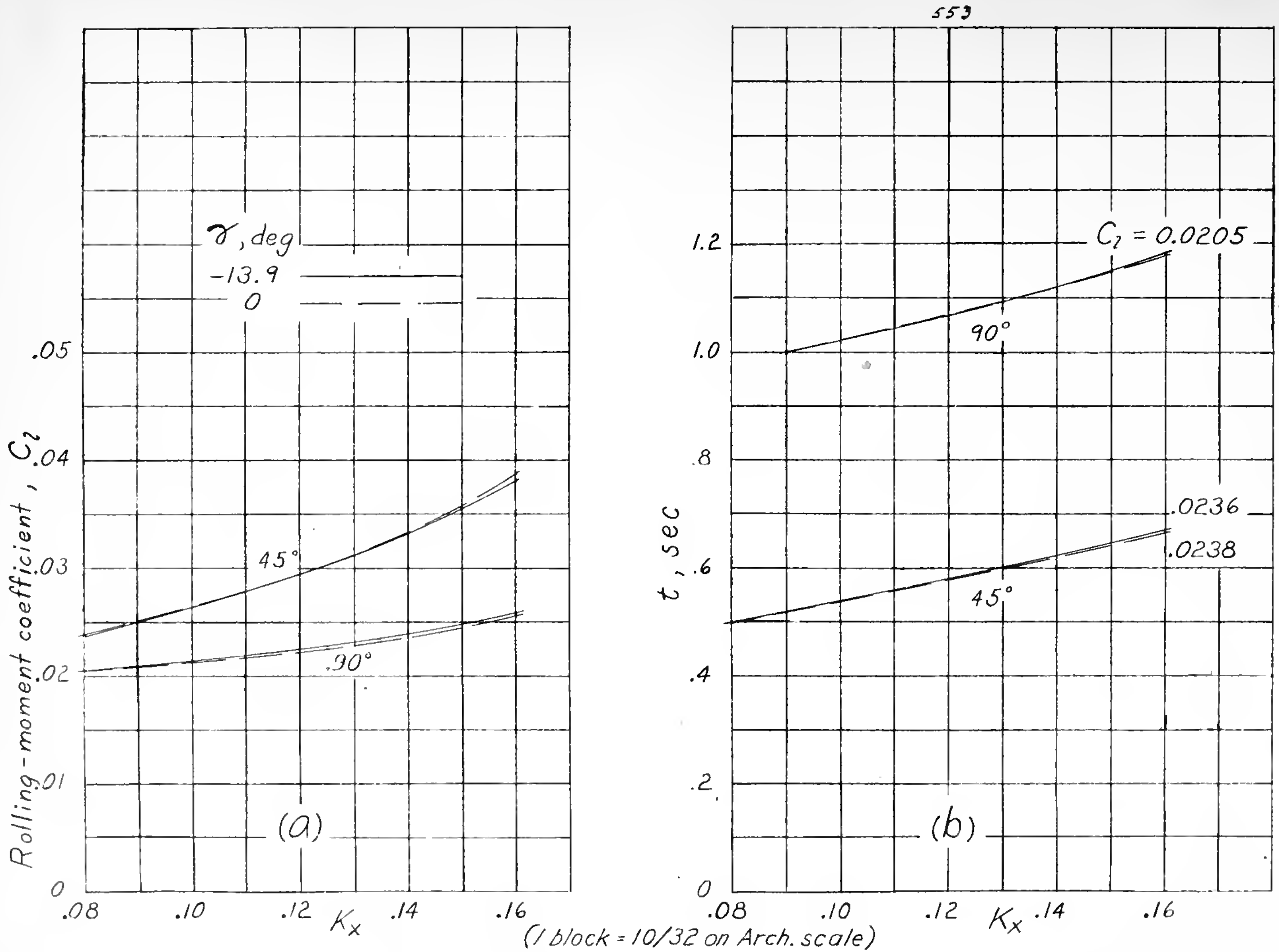
Figure 1.- The variation of rolling-moment coefficient and time to bank to 45° and 90° with altitude.



(a) The relative hinge moment necessary to bank to 45° at the end of the first half second and 90° at the end of the first second.

(b) The time to bank to 45° and 90°.

Figure 2.- The variation of relative hinge moment and time to bank to 45° and 90° with altitude.



(a) The rolling moment necessary to bank to 45° at the end of the first half second and 90° at the end of the first second.

(b) The time to bank to 45° and 90°.

Figure 3.- The variation of the rolling-moment coefficient and the time to bank to 45° and 90° with the radius of gyration about the X axis.